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FINAL REPORT FOR ONR PROJECT NOOOO14-89-J-1691 (FY89-90): PHOTOSYNTHETIC PIGMENT INVESTIGATIONS IN THE NORTH ATLANTIC OCEAN

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ABSTRACT

The major focus of the "Marine Bioluminescence and Upper Ocean Physics" Program (Marine Light-Mixed Layer, MLML) is to understand and predict the spatio-temporal variability of the bioluminescent light field in the upper ocean. Successful fulfillment of this objective requires the development of mechanistic models which describe interactions among important optical, biological and physical processes. The major scientific objectives of this current research task are to: (1) develop models for accurately predicting phytoplankton absorption signatures, algal biomass and primary production rates from optical measurements performed from untended moorings; (2) use plant pigments as diagnostic markers for investigating phytoplankton distributions at the "class" level; (3) estimate rates of upper-ocean mixing from measurements of diadinoxanthin and diatoxanthin concentrations; (4) assess the usefulness of peridinin as a "biomarker" for mapping bioluminescent dinoflagellate distributions; and (5) identify the principal agents responsible for the absorption of spectral irradiance at the MLML mooring site.

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1.0 INTRODUCTION

The primary focus of Project MLML is to improve our predictive capabilities regarding bioluminescence in the upper ocean. This will be achieved by identifying the important "physical forcings" (e.g., vertical mixing, destratification/restratification, turbulent mixing and horizontal advection) which act on oceanic plankton and quantifying their subsequent biological and optical responses. By understanding the interactions among optical and biological properties, models can be developed which describe biological distributions/rate processes from rapid, remotely-sensed optical parameters. While some of the MLML objectives are similar to those of the BIOWATT program, the proposed field area is considerably different. The important distinctions of the proposed mooring location (59.5°N, 21.0°W) are its (1) physical complexity (Dickson *et al.*, 1990), (2) strong seasonality (Williams, 1988), (3) biological communities (Williams, 1988) and (4) potential sources of bioluminescence (ONR Bioluminescence Workshop, 1990). As described below, the analysis of plant pigment distributions can provide valuable insight into the factors which control the attenuation and generation of light at the proposed mooring site. The four working hypotheses for the MLML project are given below:

(1) The organisms responsible for most (>80%) of the bioluminescence potential during the productive season are photosynthetic and heterotrophic dinoflagellates. The bulk of the remainder is due to omnivorous and carnivorous copepods whose life cycles are not "tuned" to the spring bloom.

(2) The productive season for phytoplankton exists from late May through September. This productivity in maintained through mesoscale and event-scale variability which maintains a constant, but locally patchy, nutrient supply.

(3) At large spatio-temporal scales (seasons, provinces) bioluminescence potential is related to heterotrophic potential (i.e., it can be predicted from some measure of heterotrophy)

(4) At small spatio-temporal scales (days, tens-of-kilometers), because of the small size of the predominant organisms, bioluminescence potential is directly correlated with chlorophyll *a* concentration horizontally and vertically.

Photosynthetic pigments are the dominant absorbing compounds found in phytoplankton, hence their distributions are important in determining water column optical properties. In recent years high-performance (pressure) liquid chromatography (HPLC) has been shown to be the definitive method for separating and quantifying plant pigments (e.g., Mantoura and Llewellyn, 1983). Detailed analyses of photosynthetic pigment compositions, as those obtained by HPLC, can be used for "chemotaxonomically" characterizing unidentified algal clones (Hooks *et al.*, 1988; Bidigare, 1989; Shapiro *et al.*, 1989; Bidigare *et al.*, 1990a); examining phytoplankton distributions in natural waters (Gieskes and Kraay, 1986; Bidigare *et al.*, 1990b; Ondrusek *et al.*, 1990; Siegel *et al.*, 1990); estimating the phytoplankton absorption coefficient ($a_{ph}(\lambda)$; Bidigare *et al.*, 1990c); and bio-optically modeling primary production rates (Bidigare *et al.*, 1987; Smith *et al.*, 1989). HPLC pigment analysis is rapid, sensitive and compatible for shipboard use. *For Project MLML, the determination of phytoplankton pigment concentrations will be especially useful for*:

(1) Inferring temporal and depth-dependent variations in phytoplankton distribution at the "class" level;

(2) Examining photosynthetic dinoflagellate distributions, many of which are important sources of bioluminescence;

(3) Identifying the presence of coccolithophorids, an important group of light-scatterers;

(4) Assessing the influence of vertical mixing on the distribution and photoadaptive state of resident phytoplankton; and

(5) Bio-optically modeling primary production rates from remotely-deployed optical sensors.

2.0 RESULTS FROM PREVIOUS WORK

During FY1989-90 the following tasks were completed: (1) analyzed suspended particulate and seawater samples collected during the MLML mooring deployment/recovery cruises for photosynthetic pigment and nutrient contents (see below); **(2)** determined the photosynthetic pigment compositions of a variety of algal clones isolated from oceanic waters in order to expand our library of "chemotaxonomic" markers (Shapiro *et al.*, 1989; Bidigare *et al.*, 1990a); **(3)** continued refinement of our spectrally-dependent bio-optical production model for its application to mooring-derived data (Smith *et al.*, 1989); **(4)** evaluated the importance of "pigment package" effects in natural phytoplankton populations through statistical analysis of data collected during phase II of the Biowatt program (Bidigare *et al.*, 1990c); and **(5)** examined "chromatic" photoadaptation and "enhancement" effects on wavelength-dependent quantum yield and carbon fixation rates in three species of marine phytoplankton (Bidigare *et al.* 1989; Schofield *et al.* 1990). Specific results are outlined below:

2.1 Field Studies

Plant pigment data collected during the MLML mooring deployment cruise (April 1989) revealed that the upper water column was well mixed (mixed layer depth was ~100 m). The quantitatively important algal pigments measured (and their respective concentrations) were: chlorophyll *a* (287 ng/L); chlorophyll *b* (68 ng/L); 19'-hexanoyloxyfucoxanthin (67 ng/L); and chlorophyll *c* (50 ng/L). Fucoxanthin, 19'-butanoyloxyfucoxanthin, prasinoxanthin,

diadinoxanthin, violaxanthin, alloxanthin and zeaxanthin were present at lower concentrations (6-36 ng/L), and peridinin was present at trace levels. These pigment data were used in conjunction with published accessory pigment-to-chlorophyll *a* ratios to estimate algal composition. These calculations suggest that prymnesiophytes, diatoms, prasinophytes, chrysophytes, cryptophytes and cyanophytes comprised 28, 26, 22, 11, 9 and 4% of the chlorophyll *a* biomass, respectively (Figure 1). Less than 1% of the chlorophyll *a* biomass was contributed by photosynthetic dinoflagellates and prochlorophytes.

For the mooring recovery cruise (September 1989) chlorophyll *a* pigment biomass was ~2-fold higher in surface waters and undectable at depths >100 m (mixed layer depth was ~75 m). The quantitatively important algal pigments measured in the upper 50 m (and their respective concentrations) were: chlorophyll *a* (572 ng/L); fucoxanthin (164 ng/L); 19'-hexanoyloxyfucoxanthin (132 ng/L); chlorophyll *b* (103 ng/L); and chlorophyll c (89 ng/L). Peridinin, 19'-butanoyloxyfucoxanthin, prasinoxanthin, diadinoxanthin, alloxanthin, lutein and zeaxanthin were present at lower concentrations (8-41 ng/L). These data suggest (see above) that diatoms, prymnesiophytes, prasinophytes, chrysophytes, dinoflagellates, cryptophytes and cyanobacteria comprised 34, 27, 18, 9, 6, 4 and 2% of the chlorophyll *a* biomass, respectively (Figure 1). While concentrations of peridinin were higher during the September cruise (36 ng/L vs trace levels), photosynthetic dinoflagellates contributed only 6% to the chlorophyll *a* biomass.

Composite nitrate and silicate distributions measured for the mooring deployment and recovery cruises are shown in Figure 2.

Concentrations of nitrate and silicate in the upper ~70 m during the September cruise were depleted by 385 and 295 mmoles/m^2, respectively, relative to the April cruise. These depletions were most likely caused by phytoplankton removal.

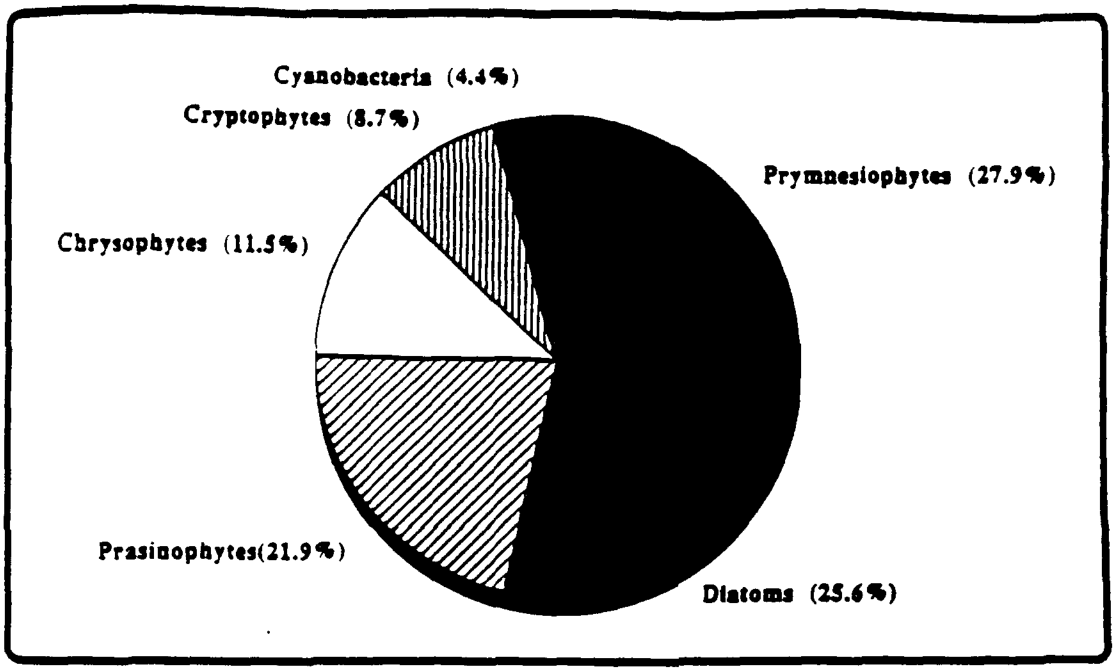
2.2 Laboratory Studies

We participated in collaborative laboratory studies during FY1989-90 with Dr. B.B. Prezelin (UCSB) and Dr. R.R.L. Guillard (CCMP). For the former, representative marine phytoplankton were grown under different light regimes, and measurements of pigments, absorption, PvsI responses and carbon action spectra were performed to examine the variability of quantum yield and test the accuracy of the bio-optical production model. The work we have performed thus far has been productive and resulted in two manuscripts (Bidigare *et al.*, 1989; Schofield *et al.*, 1990).

Select clones of eukaryotic ultraphytoplankton were grown in batch culture by Drs. R.R.L. Guillard and M.D. Keller (Center for Culture of Marine Phytoplankton) and sent to our laboratory for the analysis of photosynthetic pigment composition. Results from this work are summarized in Shapiro *et al.* (1989) and Bidigare *et al.* (1990a). Such studies have been critical for the interpretation of pigment distributions measured during the BIOWATT and MLML projects, and have extended the use of pigments as "biological source markers" for marine phytoplankton.

MLML Mooring Deployment Cruise (April 1989)

PHYTOPLANKTON COMPOSITION
(% Total Chlorophyll a Biomass)



MLML Mooring Recovery Cruise (September 1989)

PHYTOPLANKTON COMPOSITION
(% Total Chlorophyll a Biomass)

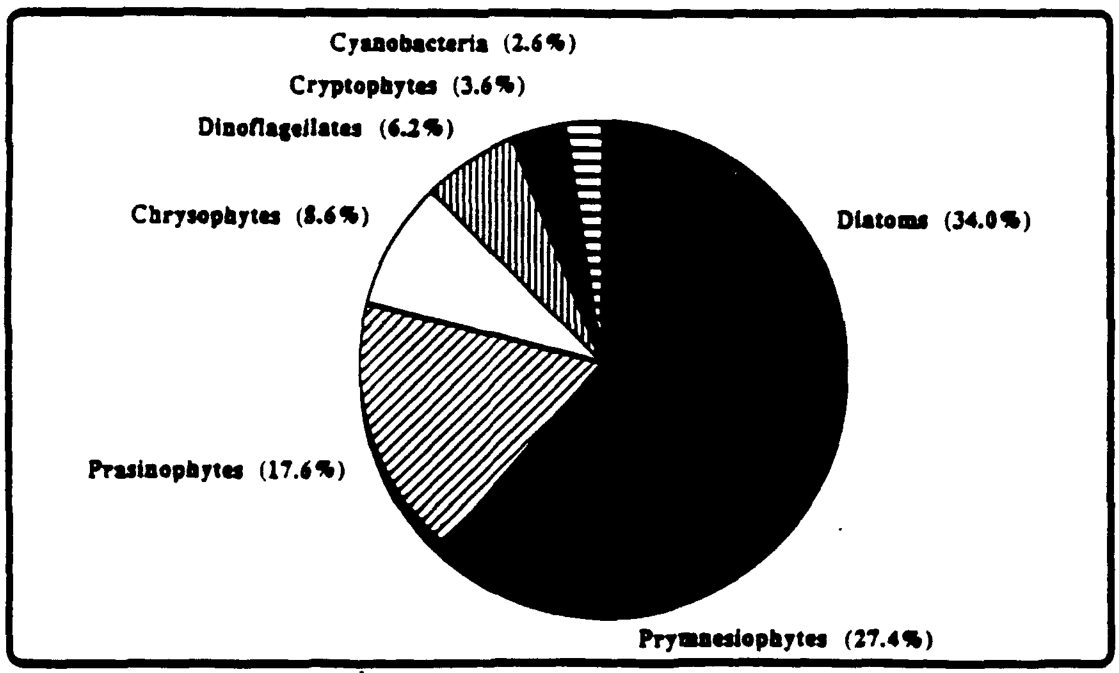
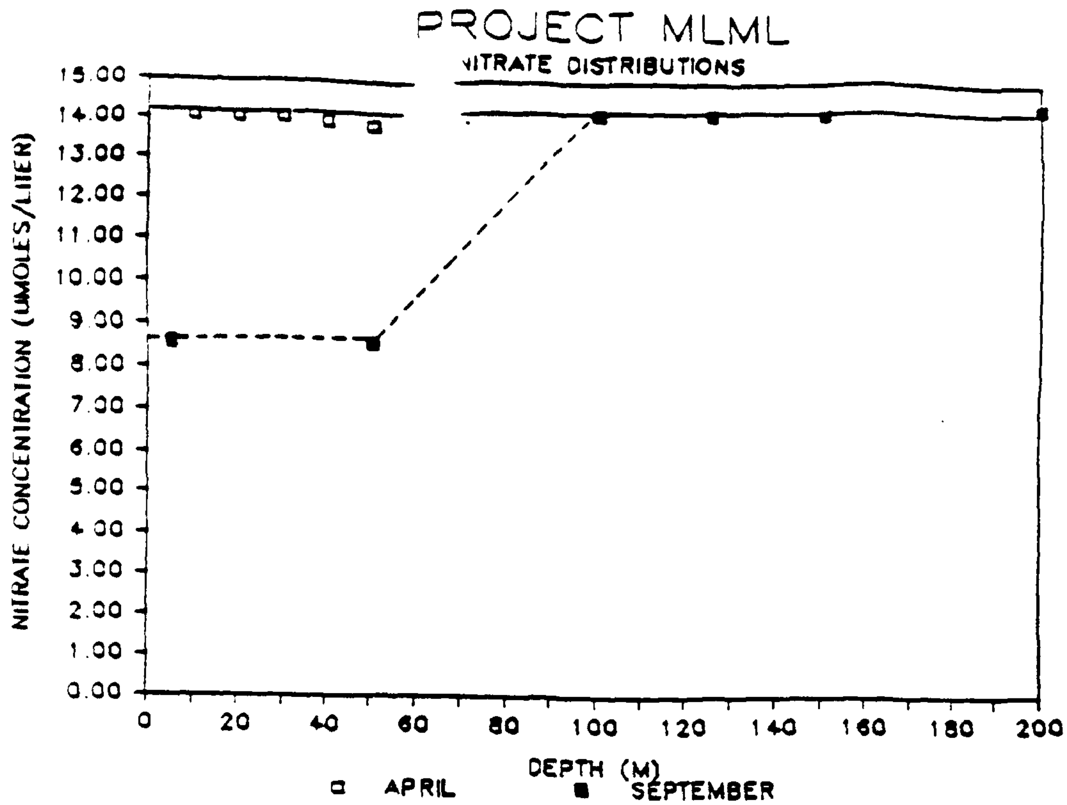


Figure 1. Phytoplankton composition (% chlorophyll *a* biomass) calculated for the mooring deployment and recovery cruises.



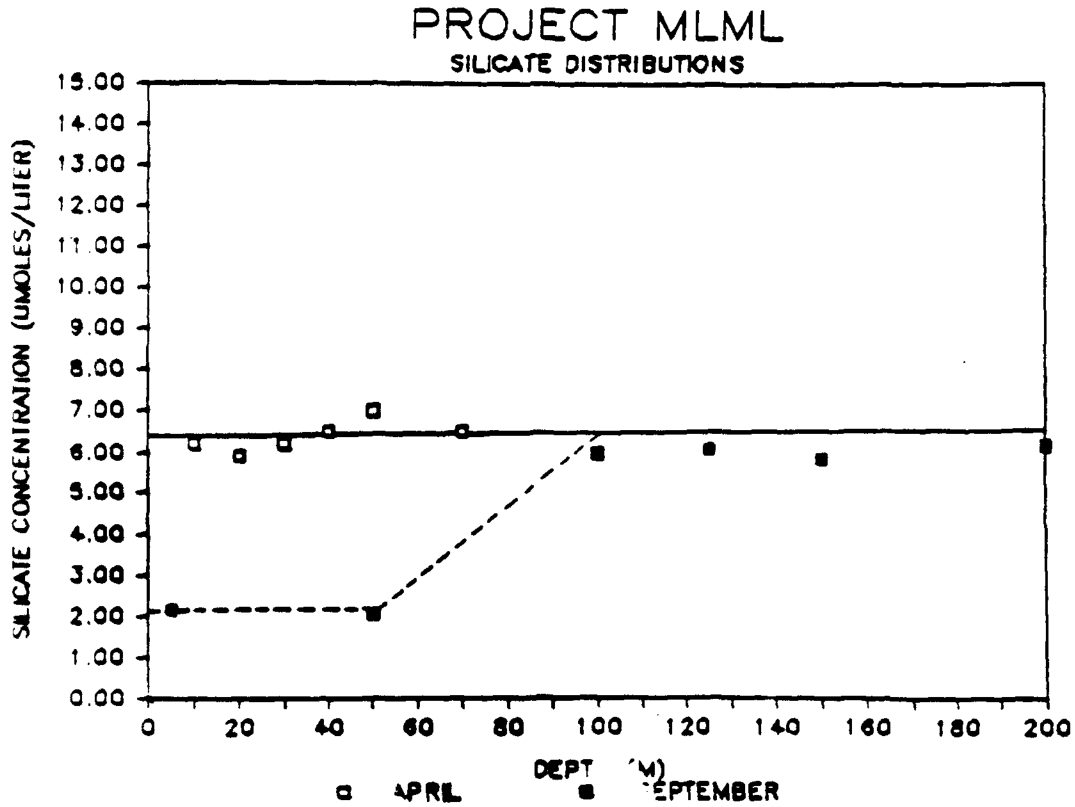


Figure 2. Vertical distributions of nitrate and silicate concentrations (micromoles/L) for the mooring deployment and ...

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